Vascular Ultrasound

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KEYWORDS

• Ultrasonography • Point-of-care ultrasound • Doppler • Deep venous thrombosis
• Arterial occlusion • Pseudoaneurysm • Aneurysm • Hematoma

KEY POINTS

- Compression ultrasonography is the test of choice to diagnose deep vein thrombosis.
- Point-of-care ultrasound has high sensitivity and specificity for diagnosing both acute arterial occlusion and pseudoaneurysm.

Video content accompanies this article at http://www.emed.theclinics.com.

INTRODUCTION

Peripheral vascular disease affects more that 8.5 million people in the United States and peripheral vascular emergencies encompass a broad range of conditions affecting the venous or arterial system.[1] Vascular point-of-care ultrasound (POCUS) is an important modality in the evaluation of these vascular emergencies. This article provides information on the use of ultrasonography in the diagnosis of peripheral vascular emergencies including deep venous thrombosis, peripheral artery occlusion, aneurysm, pseudoaneurysm, and hematoma.

DISCUSSION

Lower Extremity Venous Compression Ultrasonography

Background

One of the most common uses of vascular POCUS in the ED is lower extremity compression ultrasound. Ultrasound is the imaging modality of choice for the evaluation of deep vein thrombosis (DVT) due to its high accuracy, safety, speed, and noninvasive nature.[1] The ability to diagnose DVT accurately and expediently is critical given

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the high morbidity and mortality of venous thromboembolic disease. Of patients with diagnosed DVT, the 1-month mortality is 5% and the 1-year mortality is 10%.[2] For patients that go on to develop pulmonary embolism (PE), the mortality rate doubles.[2] Up to 50% of patients with DVT will develop post-thrombotic syndrome, characterized by venous insufficiency, ulceration, pain, and swelling, leading to significant morbidity.[3] Early diagnosis and appropriate initiation of treatment are critical.

Signs and symptoms of DVT or PE are common presenting complaints in the ED and are familiar work-ups for many physicians. In the ED, the ability to evaluate for DVT with POCUS allows for quicker disposition and more timely treatment.[4,5] Many hospitals do not have the ability to perform radiology or vascular laboratory studies on nights and weekends; thus, patients are often unnecessarily anticoagulated in preparation for future outpatient ultrasound studies. Moreover, fewer than 30% of high-risk patients follow up for outpatient imaging, leaving these patients at risk for propagation, complications, and poor outcomes.[6] Moreover, patients with concern for PE may benefit from assessment for DVT, as a positive POCUS for DVT can allow them to be treated while being further stabilized or prepared for additional imaging. Therefore, ED clinicians should be facile in performing this procedure, with data suggesting the accuracy of the emergency physician (EP)-performed POCUS is 96% sensitive and 97% specific.[7]

Procedural approach

There are many described sonographic protocols for evaluation of DVT. Whole leg duplex ultrasonography is the traditional comprehensive study performed in a vascular laboratory or radiology department. In this study, all of the proximal and distal deep veins from the groin to the ankle are compressed in short segment intervals with the addition of Doppler throughout. The first studies of POCUS described a 2-point protocol which involves evaluation of the common femoral vein (CFV) and the popliteal veins (PV) alone.[8] A 2-region ultrasound protocol evaluates these femoral and popliteal regions within 3 to 5 cm from the CFV and the PV with several compressions. Occasionally "2-point" and "2-region" may be used interchangeably in the literature.[9] More comprehensive still is the 3-region protocol, interchangeably called "extended compression ultrasonography," which expands upon the 2-region examination by tracking the femoral vein through the thigh.[9] Roughly 6% of DVTs will remain undiagnosed and untreated with a 2-region versus a 3-region examination, predominantly from isolated femoral vein thrombosis.[10,11] This is the preferred technique due to its superior accuracy and relative ease of performing the extended protocol.[12]

To perform this examination, the patient should be placed in a gown and a towel or sheet should be used to protect the patient's clothing from gel and to cover sensitive areas which are not being scanned. Patients should be supine for the femoral portion of the examination but can be prone or supine for the popliteal region. For evaluation of the popliteal region, the patient should externally rotate at the hip and slightly flex at the knee to expose the posterior knee. Patients with limited hip mobility may not be able to do this, so they can lay prone, let the leg hang over the side of the bed, or an assistant can help lift the leg for the popliteal portion. In most cases, a linear transducer is used; however, the curvilinear transducer can be employed if additional depth of view is required.

The sonographic diagnosis of lower extremity DVT is made by visualizing all of the veins within the deep venous system and applying downward compression with the probe to assess for compressibility. The operator begins by identifying each vessel in the vessel's transverse plane. When appropriate compressive force is applied to a vein in question, the adjacent artery will demonstrate slight deformity and the vein will be completely obliterated (**Fig. 1**) (Video 1). If the vein does not

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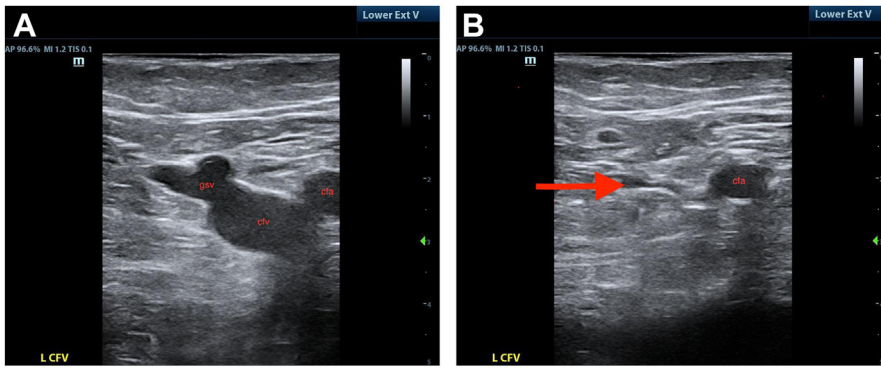

Fig. 1. (*A*) The common femoral vein (CFV) at the junction with the great saphenous vein (GSV) adjacent to the common femoral artery (CFA) shown without compression. (*B*) With compression (*right image*), the common femoral vein is completely obliterated (indicated by the *red arrow*) indicative of no DVT at this location.

completely compress with this maneuver, this is diagnostic for a DVT (**Fig. 2**) (Video 2).

A 3-region protocol begins at the CFV high in the groin, just distal to the inguinal ligament. At this location, the common femoral artery (CFA) is seen immediately adjacent to the vein (**Fig. 3**). Compression should be applied in this most proximal area. Slightly more distal from this location, the great saphenous vein (GSV) can be seen joining the CFV entering anteriorly. The GSV resides in its own fascial compartment which takes on a roughly ovoid shape with lateral points, resembling an eye, which allows it to be distinguished from other adjacent accessory veins.[13] Compression should be applied at the saphenofemoral junction ensuring that the veins are completely compressible (see **Fig. 1**). Throughout the examination, veins are routinely evaluated at sites of confluence and turbulence, as these are favorable sites for clot formation. A thrombus visualized within the GSV near the saphenofemoral junction, though technically a superficial vein, represents a thrombus that should be treated due to its proximity to

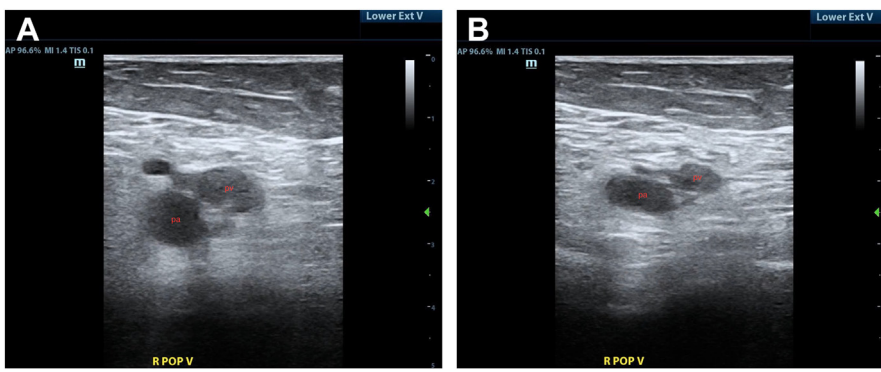

Fig. 2. (*A*) The popliteal artery (PA) and vein (PV) are imaged initially without compression. (*B*) The PA and PV are seen with compression. Incomplete compression of the PV is indicative of a DVT at this location. Note that appropriate compressive force is applied to the PA to cause slight deformation.

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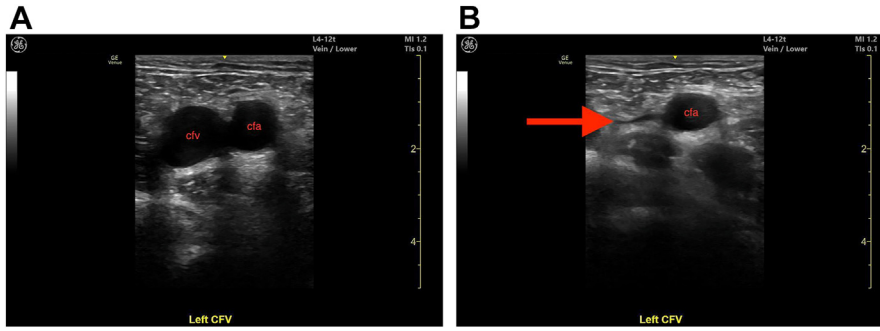

Fig. 3. (*A*) The common femoral vein (CFV) and the common femoral artery (CFA) seen in a transverse plane without compression. (*B*) The CFV is completely compressed. *Red arrow* indicates the CFV during compression, note the anterior and posterior walls contacting one another.

the CFV.[14] Immediately after the saphenofemoral junction, the CFV can be compressed again for complete evaluation.

As the operator moves the probe more distal on the lower extremity, the CFA is seen to bifurcate more proximally than the CFV. Following the arterial bifurcation, the CFV will bifurcate more distally into the femoral vein and deep femoral vein (**Fig. 4**). Previously, the femoral vein was called the "superficial femoral vein." However, applying the term "superficial" to a vein of the deep system can be confusing, leading to incorrect courses of action; therefore, the preferred term is now "femoral vein."[13] The femoral vein and the deep femoral vein should be fully compressed to evaluate for DVT at this proximal location. For a 2-region protocol, this vein is compressed only for a few centimeters. For a 3-region protocol, the femoral vein can be followed distally through the thigh with periodic compression (proximal, mid, and distal femoral vein) until the vein is seen to dive deep through the adductor canal in the mid-thigh.

From here, the popliteal area is assessed. The popliteal space houses the popliteal artery (PA) and (PV). The PV is more superficial than the PA. Compression should be applied in this area (**Fig. 5**). The 3 veins that converge to create the PV are the anterior and posterior tibial veins and the peroneal veins. This trifurcation of vessels should also be sought and impressed to confirm compressibility at this confluence. The venous anatomy in this area can vary quite substantially.[15,16]

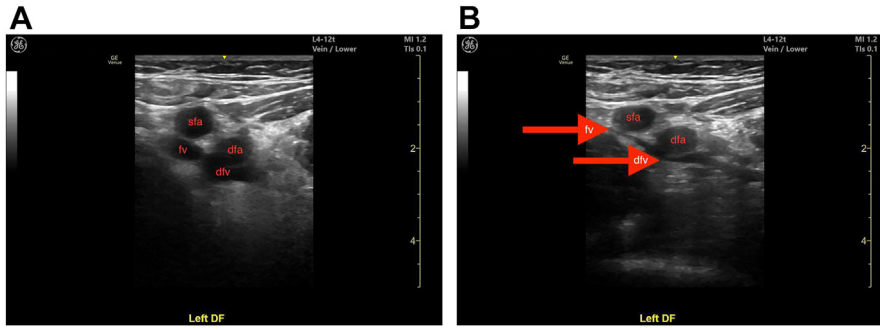

Fig. 4. (*A*) Distal to the common femoral vein (CFV) the four vessels that will be visualized are the superficial femoral artery, the deep femoral artery, the femoral vein and the deep femoral vein. (*B*) With compression, the femoral vein (FV) and deep femoral vein (DFV) will compress (as denoted by the *red arrows*) while the superficial femoral artery (SFA) and deep femoral artery (DFA) will remain patient.

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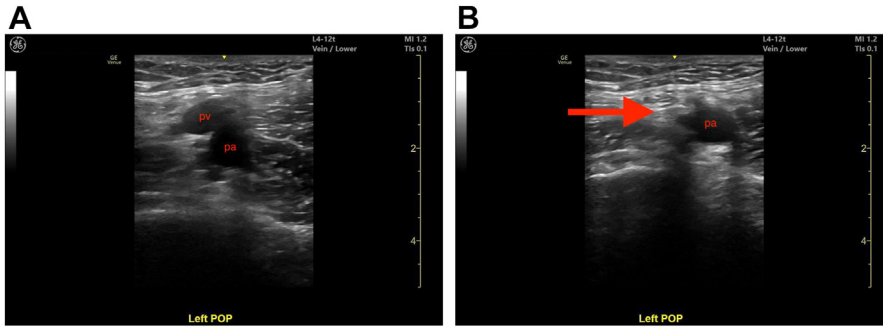

Fig. 5. In the popliteal space, the popliteal vein (PV) is visualized in a position more superficial than the popliteal artery. (*A*) The PV is uncompressed and (*B*) fully compressed (*red arrow*).

Ultrasound findings

Acute DVTs appear anechoic or hypoechoic and no sonographic signal may be seen within the vessel; however, a clot can still be present, hence the need for compression. Chronic DVTs, in contrast, are likely to have a hyperechoic appearance (**Fig. 6**) (Video 3). Color or spectral Doppler may be utilized to aid in identification of vessels or to confirm suspicion of occlusive or partially occlusive thrombus (**Fig. 7**) (Video 4). Augmentation has also been traditionally used to evaluate for DVT. This technique utilizes color or spectral Doppler to visualize augmented venous return through a vessel upon compression of the distal limb. After applying Doppler to the affected vessel, the operator gently squeezes the patient's lower leg to stimulate venous return (**Fig. 8**). If no venous return is visualized in the area, it is assumed that there is a DVT distal to the area of interrogation blocking venous return. Despite the proposed mechanism, literature suggests the addition of augmentation to an ultrasound examination rarely has a meaningful impact on a lower extremity venous examination.[17]

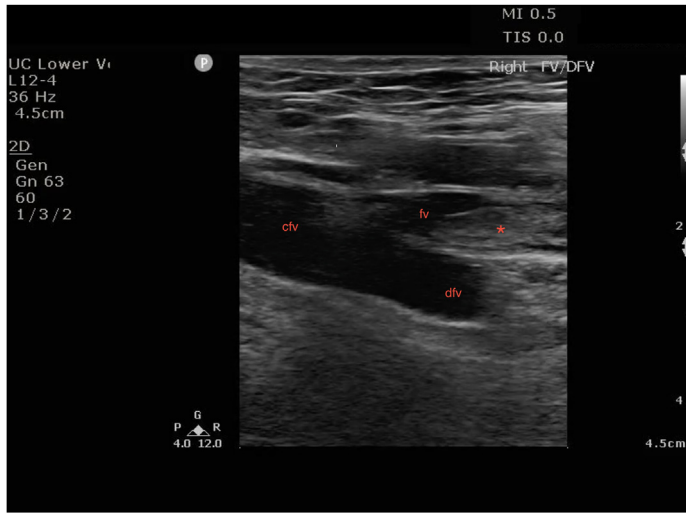

Fig. 6. A hyperechoic chronic-appearing clot (*asterisk*) is seen in the FV. The CFV is imaged in the longitudinal plane of the vessel demonstrating the confluence of the FV and DFV.

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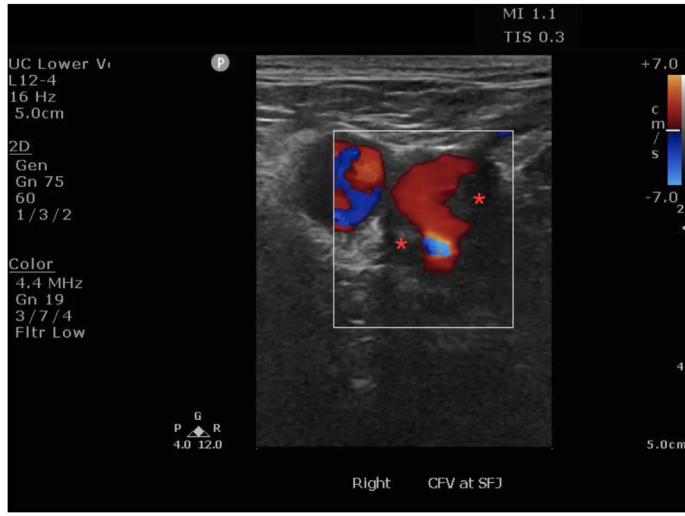

Fig. 7. The CFA and CFV are seen with color Doppler applied. The CFV demonstrates areas within the vein that do not demonstrate Doppler flow (*asterisk*) and indicate partial occlusion.

It is important as an emergency physician (EP) to be aware of other findings which may appear on a POCUS study done to evaluate for DVT. First, superficial veins may have thrombosis within them. Not all superficial venous thrombosis requires full anti-coagulation, so patient risk factors should be taken into consideration and the patient should be monitored. Next, lymph nodes are often seen particularly in the groin when performing POCUS. Lymph nodes have an ovoid appearance with a hypoechoic rim surrounding a hyperechoic hilum. When color Doppler is applied, vascular flow can be seen within the central hilum (Fig. 9). Lymph nodes are non-compressible and if they are incompletely or only partially evaluated, they can be mistaken for a DVT. The operator should fan or sweep proximal and distal on the structure. Additionally,

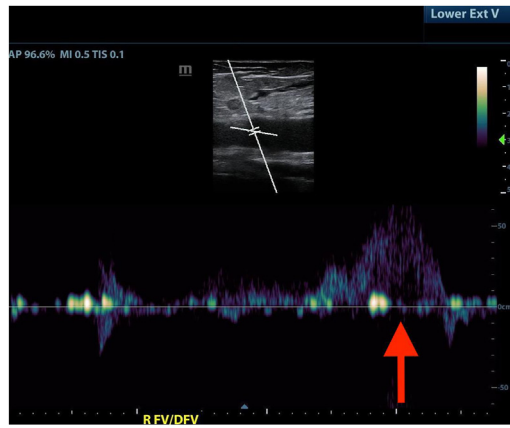

Fig. 8. A spectral Doppler tracing depicts the FV in a longitudinal plane. Compressive force distal in the leg creates vigorous venous return as seen in the spectral tracing at the arrow.

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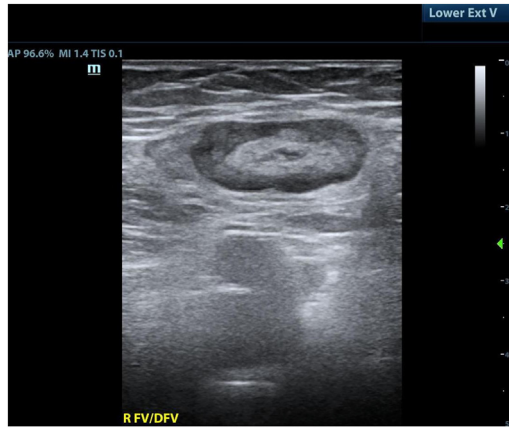

Fig. 9. Occasionally, lymph nodes are seen on lower extremity compression ultrasound examinations. They classically have a hypoechoic rim surrounding an echogenic hilum and are ovoid in shape.

there are often alternative findings discovered when performing DVT studies. As many as 23% of POCUS studies may demonstrate non-thrombotic findings, the most common of these being edema, a Baker's cyst, and fluid collections.[18] It is advisable to ask the patient where their site of maximal pain is located and systematically evaluate that area as this will aid in establishing a final diagnosis in many patients.

Upper Extremity Venous Compression Ultrasonography

Upper extremity DVT is less common than lower extremity DVT, more likely to be associated with a central venous catheter, and less likely to have a concomitant pulmonary embolism.[19] Sonographic evaluation of the upper extremity venous system is more nuanced and complex than it is in the lower extremities. The upper extremity vascular system includes several areas which are non-compressible thus these areas require spectral Doppler waveform analysis to visualize changes in the venous waveform that suggest a thrombus proximal or distal to the areas evaluated.[20] The bilateral vessels of the upper extremity and neck are evaluated including the internal jugular, innominate or brachiocephalic, subclavian, axillary, brachial, basilic, and cephalic veins.[20] Sonographic evaluation by EPs is occasionally performed for this indication; however, this advanced skill is not routinely performed by EPs.

Arterial Ultrasound

Background

Although DVT is a common cause of pain and lower extremity swelling, EPs should also be able to assess for arterial causes of pain as well. Acute arterial occlusion and resulting limb ischemia are true vascular emergencies that require emergent surgical intervention. Limb ischemia is most commonly the result of arterial thrombus, emboli, or trauma but can also result from vasospasm, vasculitis, and external compression from compartment syndrome.[21] Patients presenting with extremity pain at rest, pallor, decreased temperature, or capillary refill and unequal pulses should be examined for arterial occlusion or stenosis. There are currently no published guidelines or protocol for POCUS assessment of arterial pathology outside of the aorta, but radiologic assessment using duplex ultrasound, the combination of traditional B-mode imaging

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with the use of spectral Doppler, has a 95% sensitivity and 92% specificity for the diagnosis of acute arterial occlusion.[22] However, there are multiple case reports and case series demonstrating that the use of POCUS in the evaluation of acute arterial pathology expedited diagnosis and surgical consultation.[22,23]

Protocol

When evaluating the lower extremity for stenosis or occlusion, the patient should be positioned similarly to when evaluating for DVT with the leg slightly externally rotated at the hip in a "frog leg" position. Using a high-frequency linear probe when evaluating for occlusion or stenosis, the EP should evaluate key points in the lower extremity arterial system including the common femoral, femoral, popliteal, dorsalis pedis, and posterior tibial arteries with pulsed-wave Doppler to determine the level and severity of the lesion.[24]

The CFA should be visualized just distal to the inguinal ligament, lateral to the CFV. The CFA should be followed to its bifurcation into the deep femoral artery (also called the profunda femoris artery) and then followed down the anterior thigh where the femoral artery dives posteriorly in the adductor canal to become the PA. Posteriorly, the PA branches into the anterior tibial artery and the tibio-peroneal trunk, which further bifurcates to the peroneal and posterior tibial arteries. The anterior tibial artery will distally become the dorsalis pedis artery.

Ultrasound findings

Evaluation of the peripheral artery with pulsed-wave Doppler yields a classic multiphasic waveform (**Fig. 10**), composed of the rapid upstroke to the peak systolic velocity (PSV), followed by a rapid downstroke that ends in a brief reversal of flow in diastole before returning to the baseline and a small anterograde wave.[25,26] Therefore, arterial stenosis and occlusion will alter the waveform typically seen. Stenosis can be identified by the visualization of an increase in the PSV of the rapid systolic upstroke component when compared to the normal adjacent proximal segment. The degree of stenosis can be determined by the quantity of increase of the PSV (**Table 1**). **Table 2** demonstrates normal peripheral artery PSV. In a complete arterial obstruction, there will be no flow at the point of obstruction but there will be discernible changes to the arterial waveform both proximally and distally to the occlusion (**Fig. 11**).[27] Proximal to the occlusion, the waveform will have a rapid upstroke and have a high resistance pattern. Distal to the occlusion, the waveform will be dampened and monophasic.

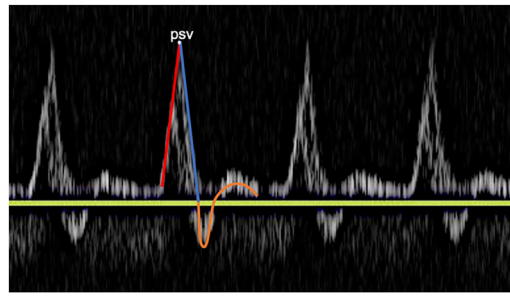

Fig. 10. Multiphasic spectral pulsed wave Doppler arterial waveform composed of the rapid upstroke (*red*) to the peak systolic velocity (PSV), followed by a rapid downstroke (*blue*) that ends in a brief reversal of flow in diastole (*orange*) before returning to the baseline and a small anterograde wave.

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Table 1
Degree of arterial stenosis

Arterial Stenosis	Peak Systolic Velocity Compared to Normal Adjacent Proximal Flow	Other Features
<50%	Increase in the peak systolic velocity (PSV) by less than double the normal range	
50%–74%	PSV doubles	Early diastolic flow reversal may be absent and spectral broadening is present
>75% stenosis	Increase in the PSV by over four 4 as much	Waveform become monophasic with increased diastolic velocity

Adapted from Kim ES, Sharma AM, Scissons R, Dawson D, Eberhardt RT, Gerhard-Herman M, Hughes JP, Knight S, Marie Kupinski A, Mahe G, Neumyer M, Poe P, Shugart R, Wennberg P, Williams DM, Zierler RE. Interpretation of peripheral arterial and venous Doppler waveforms: A consensus statement from the Society for Vascular Medicine and Society for Vascular Ultrasound. Vasc Med. 2020 Oct;25(5):484-506. https://doi.org/10.1177/1358863X20937665. Epub 2020 Jul 15. PMID: 32667274.

Other Pathology

Peripheral artery aneurysms are another cause of limb pain and edema that can be diagnosed with POCUS. Aneurysms are defined as a dilation of the vessel involving all 3 layers of the wall to greater than 1.5 times their normal caliber.[27] Aneurysms may be fusiform (circumferential dilation of the artery) or saccular (localized dilation to one side of the arterial wall). Popliteal aneurysms account for 85% of all peripheral artery aneurysms and are often associated with aneurysms in other locations, such as the abdominal aorta (40%–50%), femoral artery (40%), and contralateral PA (53%).[27]

Not to be confused with true aneurysms, pseudoaneurysms are false aneurysms, as they do not have a true vascular wall, but are perivascular fluid collections caused by a break in the vascular wall which allows blood to leak into the surrounding tissue. Although clot and soft tissue create a walled off area, a stalk or connection remains with the artery allowing blood to swirl into the cavity before returning to the vessel. Pseudoaneurysms may arise from trauma, infection, or vessel puncture. Vascular catheterization is the most common cause, with 80% of CFA pseudoaneurysms due to catheterization during interventional procedures.[21,23] Duplex ultrasound has a 94% sensitivity and a 97% specificity for diagnosis.[23,27] On B-mode imaging, the swirling of the blood flowing into the cavity and then back into the vessel creates

Table 2
Normal peripheral artery peak systolic velocities

Peripheral Artery	Peak Systolic Velocity
Common femoral	90–140 cm/s
Femoral	75–105 cm/s
Popliteal	55–80 cm/s
Tibial	45–65 cm/s

Adapted from Hodgkiss-Harlow KD, Bandyk DF. Interpretation of arterial duplex testing of lower-extremity arteries and interventions. Semin Vasc Surg. 2013 Jun-Sep;26(2-3):95-104. https://doi.org/10.1053/j.semvascsurg.2013.11.002. Epub 2013 Nov 14. PMID: 24636606.

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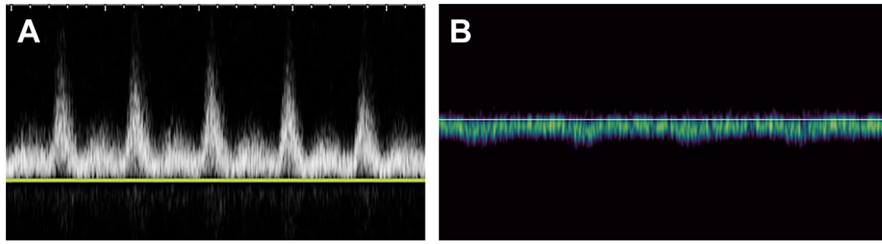

Fig. 11. (*A*) Rapid upstroke and high resistance pattern proximal to the occlusion. (*B*) Dampened and monophasic distal to the occlusion.

turbulent flow, visible as a swirling pattern (**Fig. 12**) (Videos 5 and 6). When color Doppler is applied to the pseudoaneurysm, this swirling flow appears as flow going toward the probe (red) and then away from the probe (blue), which is known as the "yin-and-yang sign." Furthermore, if pulsed-wave Doppler is placed in the stalk of the pseudoaneurysm, a "to-and-fro" pattern will be visible as well.[28] Unlike true aneurysms of the extremities which can be monitored for enlargement, a pseudoaneurysm is more likely to rupture and therefore must be treated through surgery, compression, or embolization regardless of size.[28]

Hematomas are another cause of traumatic perivascular fluid collections; however, they lack communication with a vascular structure. Hematomas appear as heterogeneous fluid collections containing debris and fibrin strands with poorly defined edges (**Fig. 13**) (Video 7).[28] B-mode and color Doppler ultrasound have demonstrated limited utility in the diagnosis of active extravasation in hematomas likely due to the low flow states or location and morphology of the extravasation. However, the use of contrast-enhanced ultrasound has demonstrated promise in identifying this potentially dangerous condition.[29,30] Contrast-enhanced ultrasound utilizes a contrast media containing microbubbles that stay within the vascular system and are visible with B-mode ultrasound imaging. Visualization of active extravasation may guide treatment including ultrasound-guided percutaneous thrombin injection to alleviate continued bleeding in these cases but more research needs to be done to determine the utility of this method in the future.

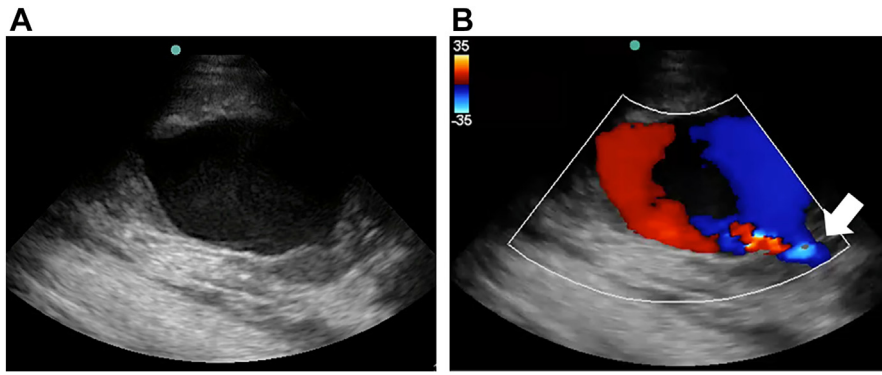

Fig. 12. Pseudoneurysm. (*A*) B-mode image demonstrating swirling blood flow within the cavity. (*B*) Color flow Doppler "to and fro" pattern, also known as the "ying yang sign." Note the stalk (*arrow*) with the blood flow moving toward the probe on the left (*red*) and then returning to the stalk on the right (*blue*).

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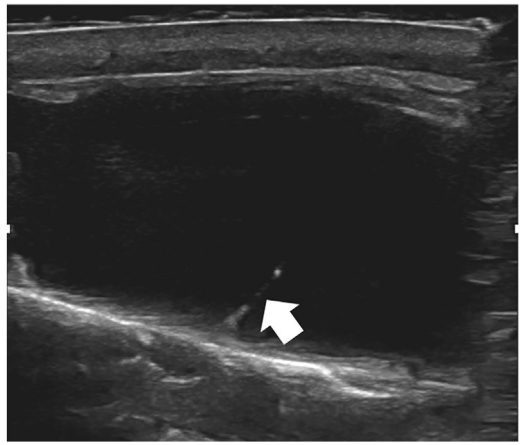

Fig. 13. Hematoma. Heterogeneous fluid collection containing debris and fibrin strands (*arrow*).

SUMMARY

This article underscores the utility of ultrasonography in diagnosing peripheral vascular emergencies, ranging from DVT to arterial occlusion, including aneurysms, pseudoaneurysms, and hematomas. With peripheral vascular disease impacting millions in the United States, prompt and accurate diagnosis in the ED is imperative. Vascular POCUS emerges as an indispensable tool in the diagnostic armamentarium of emergency medicine physicians, offering rapid assessment and high accuracy. This article summarizes comprehensive protocols and key findings in lower and upper extremity venous compression ultrasonography, arterial ultrasound, and the diagnostic nuances of peripheral artery aneurysms, pseudoaneurysms, and hematomas, equipping highly trained emergency medicine physicians with essential insights for effective patient care.

CLINICS CARE POINTS

- Peripheral vascular emergencies, including DVT, arterial occlusion, and aneurysms, pose significant risks to patient health and require prompt diagnosis and intervention to mitigate morbidity and mortality.
- Lower extremity DVT evaluation employs compression techniques to detect thrombi. Three-zone compression provides comprehensive evaluation of the lower extremity venous system and is the preferred technique.
- In upper extremity DVT evaluation, spectral Doppler waveform analysis becomes pivotal due to the anatomic complexities and non-compressible areas.
- Arterial ultrasound serves as a vital diagnostic modality for assessing arterial causes of pain. Careful assessment of pulsed-wave Doppler waveforms allows for identification of occlusions, aneurysms, pseudoaneurysms, and hematomas.
- Arterial stenosis and occlusion result in high-velocity Doppler waveforms (a rapid upstroke and relatively high peak systolic velocity) proximal to the occlusion or stenotic lesion, and a dampened or absent waveform distal to it.

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- Aneurysms are defined as a dilation of the vessel involving all 3 layers of the wall to greater than 1.5 times their normal caliber.
- Pseudoaneurysms are perivascular fluid collections caused by an interruption of the vessel wall which allows blood to leak into the adjacent tissue. Pseudoaneurysms are identified on ultrasound by a characteristic "yin and yang sign" which represents bidirectional flow within the pseudoaneurysmal defect.
- Proficiency in vascular POCUS is indispensable for highly trained EPs, enhancing diagnostic acumen and facilitating expedited, targeted interventions to optimize patient outcomes in peripheral vascular emergencies.

DISCLOSURE

M.K. Frederick has nothing to disclose. L.A. Stolz has done consulting work for Philips, Caption Health, GE, Butterfly and ThinkSono. P.E. Duran-Gehring has done consulting work for Caption Health.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.emc.2024.05.011.

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